What is an Operating System?

August 26th, 2015
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http://cs162.eecs.Berkeley.edu

Greatest Artifact of Human Civilization...

3 Billion Internet Users by ...

Operating Systems at the heart of it all...
- Make the incredible advance in the underlying hardware available to a rapid evolving body of applications.
  - Processing, Communications, Storage, Interaction
- The key building blocks
  - Scheduling
  - Concurrency
  - Address spaces
  - Protection, Isolation, Security
  - Networking, distributed systems
  - Persistent storage, transactions, consistency, resilience
  - Interfaces to all devices
Example: What’s in a Search Query?

- Complex interaction of multiple components in multiple administrative domains
  - Systems, services, protocols, ...

Why take CS162?

- Some of you will actually design and build operating systems or components of them.
  - Perhaps more now than ever
- Many of you will create systems that utilize the core concepts in operating systems.
  - Whether you build software or hardware
  - The concepts and design patterns appear at many levels
- All of you will build applications, etc. that utilize operating systems
  - The better you understand their design and implementation, the better use you’ll make of them.

Goals for Today

- What is an Operating System?
  - And – what is it not?
- Examples of Operating Systems design
- What makes Operating Systems So Exciting?
- Oh, and “How does this class operate?”

What is an operating system?

- Special layer of software that provides application software access to hardware resources
  - Convenient abstraction of complex hardware devices
  - Protected access to shared resources
  - Security and authentication
  - Communication amongst logical entities

Interactive is important!
Ask Questions!

Slides courtesy of David Culler, John Kubiatowicz, AJ Shankar, George Necula, Alex Aiken, Eric Brewer, Ras Bodik, Ion Stoica, Doug Tygar, and David Wagner.
Operator ...

Switchboard Operator

Computer Operators

OS Basics: “Virtual Machine” Boundary

Software

Hardware

Memory

Processor

Networks

Displays

Inputs

OS Basics: Program => Process

Software

Hardware

Threads

Address Spaces

Windows

Processes

Files

Sockets

Processor

Memory

Networks

Displays

Inputs

Interfaces Provide Essential Boundaries

- Why do interfaces look the way that they do?
  - History, Functionality, Stupidity, Bugs, Management
  - CS152 => Machine interface
  - CS160 => Human interface
  - CS169 => Software engineering/management
- Should responsibilities be pushed across boundaries?
  - RISC architectures, Graphical Pipeline Architectures
What makes Operating Systems exciting and Challenging?

Gordon Moore (co-founder of Intel) predicted in 1965 that the transistor density of semiconductor chips would double roughly every 18 months. Called “Moore’s Law”

Microprocessors have become smaller, denser, and more powerful.

Technology Trends: Moore’s Law

People-to-Computer Ratio Over Time

From David Culler

- Today: Multiple CPUs/person!
  - Approaching 100s?

New Challenge: Slowdown in Joy’s law of Performance

VAX: 25%/year 1978 to 1986
RISC + x86: 52%/year 1986 to 2002
RISC + x86: ??%/year 2002 to present

⇒ Sea change in chip design: multiple “cores” or processors per chip
ManyCore Chips: The future is here

- Intel 80-core multicore chip (Feb 2007)
  - 80 simple cores
  - Two FP-engines/core
  - Mesh-like network
  - 100 million transistors
  - 65nm feature size
  - 24 “tiles” with two cores/tile
  - 24-router mesh network
  - 4 DDR3 memory controllers
  - Hardware support for message-passing

• “ManyCore” refers to many processors/chip
  - 64? 128? Hard to say exact boundary
• How to program these?
  - Use 2 CPUs for video/audio
  - Use 1 for word processor, 1 for browser
  - 76 for virus checking???
• Parallelism must be exploited at all levels

Moore’s Law Extrapolation
- Potential power density reaching amazing levels!
- Flip side: Battery life very important
  - Moore’s law can yield more functionality at equivalent (or less) total energy consumption

Another Challenge: Power Density

Power Density Becomes Too High to Cool Chips Inexpensively

Storage Capacity

Retail hard disk capacity in GB

Network Capacity

### Internet Scale: .96 Billion Hosts

**Internet Domain Survey Host Count**

- **996,230,757** hosts as of July 2013

Source: Internet Systems Consortium (www.isc.org)


### Internet Scale: Almost 2.5 Billion Users!

**WORLD INTERNET USAGE AND POPULATION STATISTICS**

*December 31, 2013*

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<tr>
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<td>13.8%</td>
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<td>7,620,480</td>
<td>24,804,226</td>
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<td>WORLD TOTAL</td>
<td>7,181,856,614</td>
<td>360,983,492</td>
<td>2,903,476,934</td>
<td>38.0%</td>
<td>678.3%</td>
<td>100.0%</td>
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</table>

**NOTES:** (1) Internet Usage and World Population Statistics are for December 31, 2013. (2) CLICK on each world region name for detailed regional usage information. (3) Demographic (Population) numbers are based on data from the US Census Bureau and local census agencies. (4) Internet usage information comes from data published by Nielsen Online, by the International Telecommunications Union, by GfK, local ICT Regulators and other reliable sources. (5) For definitions, disclaimers, navigation help and methodology, please refer to the Sites Surfing Guide. (6) Information in this site may be cited, giving the due credit to www.internetworldstats.com. Copyright © 2001 - 2014, Mirravista Marketing Group. All rights reserved worldwide.


### Not Only PCs connected to the Internet

- **Smartphone shipments now exceed PC shipments!**
  - 2011 shipments:
    - 487M smartphones
    - 414M PC clients
      - 210M notebooks
      - 112M desktops
      - 63M tablets
    - 25M smart TVs
  - 4 billion phones in the world → smartphone over next decade

### Societal Scale Information Systems (Or the "Internet of Things"?)

- The world is a large distributed system
  - Microprocessors in everything
  - Vast infrastructure behind them

**Internet Connectivity**

**Scalable, Reliable, Secure Services**

- Databases
- Information Collection
- Remote Storage
- Online Games
- Commerce

**MEMS for Sensor Nets**
Who am I?

- Professor John Kubiatowicz (Prof “Kubi”)
  - Background in Hardware Design
    » Alewife project at MIT
    » Designed CMMU, Modified SPAR C processor
    » Helped to write operating system
  - Background in Operating Systems
    » Worked for Project Athena (MIT)
    » OS Developer (device drivers, network file systems)
    » Worked on Clustered High-Availability systems (CLAM Associates)
    » OS lead researcher for Tessellation OS
  - Peer-to-Peer
    » OceanStore project - Store your data for 1000 years
    » Tapestry and Bamboo - Find your data around globe
    » SwarmLab Global Data Plane for the Internet of Things (IoT)
  - Quantum Computing
    » Well, this is just cool, but probably not apropos

Infrastructure, Textbook & Readings

- Infrastructure
  - Website: http://cs162.eecs.berkeley.edu
  - Piazza: https://piazza.com/berkeley/fall2015/cs162
  - Webcast: Yes! Will post link when available
  - Copies in Bechtel
- Online supplements
  - See course website
  - Includes Appendices, sample problems, etc.
  - Networking, Databases, Software Eng, Security
  - Some Research Papers!

CS162 Team - GSIs:

- William Liu
  - Head GSI
  - Section 109, F 2-3 @ 6 Evans
- Roger Chen
  - Section 105, F 11-12 @ 102 Latimer
  - Section 107, F 12-1 @ 179 Stanley
- Alec Mouri
  - Section 103, T 4-5 @ 102 Wurster
  - Section 108, F 1-2 @ 87 Evans
- Andrew Chen
  - Section 110, F 10-11 @ 205 Dwinelle
- Roger Chen
  - Section 105, F 11-12 @ 102 Latimer
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Syllabus

- OS Concepts: How to Navigate as a Systems Programmer!
  - Process, I/O, Networks and VM
- Concurrency
  - Threads, scheduling, locks, deadlock, scalability, fairness
- Address Space
  - Virtual memory, address translation, protection, sharing
- File Systems
  - I/O device, file objects, storage, naming, caching, performance, paging, transactions, databases
- Distributed Systems (8)
  - Protocols, N-Tiers, RPC, NFS, DHTs, Consistency, Scalability, multicast
- Reliability & Security
  - Fault tolerance, protection, security
- Cloud Infrastructure
Learning by Doing

- Individual Homework (1-2 weeks): Learn Systems Programming
  - 0. Tools, Autograding, recall C, executable
  - 1. Simple Shell
  - 2. Web server
  - ...
- Three Group Projects (Pintos in C)
  - 1. Threads & Scheduling
  - 2. User-programs
  - 3. File Systems

Getting started

- Start homework 0 immediately
  - Gets cs162-xx@cory.eecs.berkeley.edu (and other inst m/c)
  - Github account
  - Registration survey
  - Vagrant virtualbox - VM environment for the course
    » Consistent, managed environment on your machine
  - Get familiar with all the cs162 tools
  - Submit to autograder via git
- Go to section this week (starting tomorrow!)
  - Bring laptop
  - Also, watch for us to post various small help-sessions
- Waitlist ???
  - Drop Deadline: September 4th
  - If you are not serious about taking, please drop early

Group Project Simulates Industrial Environment

- Project teams have 4 members (try really hard to get 4 members - 3 members requires serious justification)
  - Must work in groups in “the real world”
  - Same section much preferred
- Communicate with colleagues (team members)
  - Communication problems are natural
  - What have you done?
  - What answers you need from others?
  - You must document your work!!!
- Communicate with supervisor (TAs)
  - What is the team’s plan?
  - What is each member’s responsibility?
  - Short progress reports are required
  - Design Documents: High-level description for a manager!

Grading

- 40% midterms/Final
- 40% projects
- 15% homework
- 5% participation
- Project grading
  - [10 pts] Initial design
  - [10 pts] Design review
  - [10 pts] Design document
  - [60 pts] Code (3 checkpoints)
  - [10 pts] Final design
- Submission via git push to release branch
  - Triggers autograder
- Regular git push so TA sees your progress
Personal Integrity

- UCB Academic Honor Code: "As a member of the UC Berkeley community, I act with honesty, integrity, and respect for others."


CS 162 Collaboration Policy

- Explaining a concept to someone in another group
- Discussing algorithms/testing strategies with other groups
- Helping debug someone else's code (in another group)
- Searching online for generic algorithms (e.g., hash table)
- Sharing code or test cases with another group
- Copying OR reading another group's code or test cases
- Copying OR reading online code or test cases from prior years

We compare all project submissions against prior year submissions and online solutions and will take actions (described on the course overview page) against offenders

Typical Lecture Format

- 1-Minute Review
- 20-Minute Lecture
- 5-Minute Administrative Matters
- 25-Minute Lecture
- 5-Minute Break (water, stretch)
- 25-Minute Lecture
- Instructor will come to class early & stay after to answer questions

Lecture Goal

Interactive!!!
**What is an Operating System?**

- **Referee**
  - Manage sharing of resources, Protection, Isolation
    » Resource allocation, isolation, communication

- **Illusionist**
  - Provide clean, easy to use abstractions of physical resources
    » Infinite memory, dedicated machine
    » Higher level objects: files, users, messages
    » Masking limitations, virtualization

- **Glue**
  - Common services
    » Storage, Window system, Networking
    » Sharing, Authorization
    » Look and feel

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**Challenge: Complexity**

- Applications consisting of...
  - ... a variety of software modules that ...
  - ... run on a variety of devices (machines) that
    » ... implement different hardware architectures
    » ... run competing applications
    » ... fail in unexpected ways
    » ... can be under a variety of attacks

- Not feasible to test software for all possible environments and combinations of components and devices
  - The question is not whether there are bugs but how serious are the bugs!

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**A modern processor: SandyBridge**

- Package: LGA 1155
  - 1155 pins
  - 95W design envelope
- Cache:
  - L1: 32K Inst, 32K Data (3 clock access)
  - L2: 256K (8 clock access)
  - Shared L3: 3MB - 20MB (not out yet)
- Transistor count:
  - 504 Million (2 cores, 3MB L3)
  - 2.27 Billion (8 cores, 20MB L3)
- Note that ring bus is on high metal layers - above the Shared L3 Cache

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**Functionality comes with great complexity!**

SandyBridge I/O Configuration
### Example: Some Mars Rover (“Pathfinder”) Requirements

- **Pathfinder hardware limitations/complexity:**
  - 20Mhz processor, 128MB of DRAM, VxWorks OS
  - cameras, scientific instruments, batteries, solar panels, and locomotion equipment
  - Many independent processes work together
- **Can’t hit reset button very easily!**
  - Must reboot itself if necessary
  - Must always be able to receive commands from Earth
- **Individual Programs must not interfere**
  - Suppose the MUT (Martian Universal Translator Module) buggy
  - Better not crash antenna positioning software!
- **Further, all software may crash occasionally**
  - Automatic restart with diagnostics sent to Earth
  - Periodic checkpoint of results saved?
- **Certain functions time critical:**
  - Need to stop before hitting something
  - Must track orbit of Earth for communication
- **A lot of similarity with the Internet of Things?**
  - Complexity, QoS, Inaccessibility, Power limitations … ?

### How do we tame complexity?

- **Every piece of computer hardware different**
  - Different CPU
    - Pentium, PowerPC, ColdFire, ARM, MIPS
  - Different amounts of memory, disk, ...
  - Different types of devices
    - Mice, Keyboards, Sensors, Cameras, Fingerprint readers
  - Different networking environment
    - Cable, DSL, Wireless, Firewalls,…
- **Questions:**
  - Does the programmer need to write a single program that performs many independent activities?
  - Does every program have to be altered for every piece of hardware?
  - Does a faulty program crash everything?
  - Does every program have access to all hardware?
OS Tool: Virtual Machine Abstraction

Application → Virtual Machine Interface
Operating System → Physical Machine Interface

Hardware

- Software Engineering Problem:
  - Turn hardware/software quirks ⇒ what programmers want/need
  - Optimize for convenience, utilization, security, reliability, etc...
- For Any OS area (e.g. file systems, virtual memory, networking, scheduling):
  - What’s the hardware interface? (physical reality)
  - What’s the application interface? (nicer abstraction)

Virtual Machines

- Software emulation of an abstract machine
  - Give programs illusion they own the machine
  - Make it look like hardware has features you want
- Two types of “Virtual Machine”s
  - Process VM: supports the execution of a single program; this functionality typically provided by OS
  - System VM: supports the execution of an entire OS and its applications (e.g., VMWare Fusion, Virtual box, Parallels Desktop, Xen)

Process VMs

- Programming simplicity
  - Each process thinks it has all memory/CPU time
  - Each process thinks it owns all devices
  - Different devices appear to have same high level interface
  - Device interfaces more powerful than raw hardware
    » Bitmapped display ⇒ windowing system
    » Ethernet card ⇒ reliable, ordered, networking (TCP/IP)
- Fault Isolation
  - Processes unable to directly impact other processes
  - Bugs cannot crash whole machine
- Protection and Portability
  - Java interface safe and stable across many platforms

System Virtual Machines: Layers of OSs

- Useful for OS development
  - When OS crashes, restricted to one VM
  - Can aid testing programs on other OSs
What is an Operating System,... Really?

- Most Likely:
  - Memory Management
  - I/O Management
  - CPU Scheduling
  - Communications? (Does Email belong in OS?)
  - Multitasking/multiprogramming?
- What about?
  - File System?
  - Multimedia Support?
  - User Interface?
  - Internet Browser? 😊
- Is this only interesting to Academics??

Operating System Definition (Cont.)

- No universally accepted definition
- “Everything a vendor ships when you order an operating system” is good approximation
  - But varies wildly
- “The one program running at all times on the computer” is the kernel.
  - Everything else is either a system program (ships with the operating system) or an application program

Example: Protecting Processes from Each Other

- Problem: Run multiple applications in such a way that they are protected from one another
- Goal:
  - Keep User Programs from Crashing OS
  - Keep User Programs from Crashing each other
  - [Keep Parts of OS from crashing other parts?]
- (Some of the required) Mechanisms:
  - Address Translation
  - Dual Mode Operation
- Simple Policy:
  - Programs are not allowed to read/write memory of other Programs or of Operating System

Address Translation

- Address Space
  - A group of memory addresses usable by something
  - Each program (process) and kernel has potentially different address spaces.
- Address Translation:
  - Translate from Virtual Addresses (emitted by CPU) into Physical Addresses (of memory)
  - Mapping often performed in Hardware by Memory Management Unit (MMU)
Example of Address Translation

Virtual Address Space 1

Virtual Address Space 2

Translation Map 1

Translation Map 2

Physical Address Space

Address Translation Details

- For now, assume translation happens with table (called a Page Table):

- Translation helps protection:
  - Control translations, control access
  - Should Users be able to change Page Table???

Dual Mode Operation

- Hardware provides at least two modes:
  - "Kernel" mode (or "supervisor" or "protected")
  - "User" mode: Normal programs executed

- Some instructions/ops prohibited in user mode:
  - Example: cannot modify page tables in user mode
    » Attempt to modify ⇒ Exception generated

- Transitions from user mode to kernel mode:
  - System Calls, Interrupts, Other exceptions

UNIX System Structure

User Mode

- Applications (the users)
- Standard Libs
  - shells and commands
  - compilers and interpreters
  - system libraries

Kernel Mode

- Kernel
  - system-call interface to the kernel
  - signals terminal handling
  - character I/O system terminal drivers
  - file system
  - swapping block I/O system
  - disk and tape drivers
  - CPU scheduling
    - page replacement
    - demand paging
  - virtual memory

Hardware

- terminal controllers
- device controllers
- memory controllers
- physical memory
"In conclusion...

- Operating systems provide a virtual machine abstraction to handle diverse hardware
- Operating systems coordinate resources and protect users from each other
- Operating systems simplify application development by providing standard services
- Operating systems can provide an array of fault containment, fault tolerance, and fault recovery

- CS162 combines things from many other areas of computer science -
  - Languages, data structures, hardware, and algorithms